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Dr. Mr. Thomas:

NTIA has reviewed the filings on the UWB notice of proposed rulemaking (NPRM). NTIA has also had numerous meetings with the FCC, the Executive Branch agencies, the UWB developers and potential users to discuss the various spectrum issues including UWB device power constraints, operational restrictions, technical standards, frequency band of operation, certification, enforcement, and coordination. In addition, NTIA has reviewed and analyzed the need for protection of current and future Federal government radiocommunication systems that operate in the spectrum being proposed for UWB operation. A summary of the analysis is shown in Attachment 1.

Based on these filings, discussions, and the measurements and analysis contained in our reports (previously provided to the FCC), NTIA is providing a summary of our rationale for the limits being proposed on UWB to protect Global Positioning System (GPS) and non-GPS radiocommunications as shown in Attachment 1.

In addition, NTIA has also analyzed, as shown in Attachment 2, the impact of automotive radars operating at 24.125 GHz to satellite receivers operating in the 23.6-24.0 GHz band in which no stations are authorized to transmit under U.S. Footnote 246. This analysis indicates that densities as low as 10 vehicles/$km^2$ could cause interference to satellite receivers. To minimize this effect, the analysis shows that the radar EIRP must be attenuated 35 dB below (at elevation angles above 30 degrees above the horizon) the current Part 15 limit. It is recognized that the automotive radar development community plans to begin implementation of these radars on automobiles in 2005, but they can only provide approximately 25 dB attenuation by that time. To attain the additional 10 dB would require more time.

The question is how much time is required and what rules are necessary to ensure that the satellite receivers will not be impacted as the new radars are deployed over the foreseeable future. We have indicated by footnote 4 in Attachment 2, the suggested time needed to attain 5dB of the 10 dB is 5 years (2010) and the remaining 5 dB by 2014. It should be noted that National Aeronautical and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) would prefer the first 5dB

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by 2008 and the remaining 5dB by 2011. The automotive industry would prefer 5 dB by 2012 and the remaining 5 dB by 2019.

Protection is also required for the 10.60 to 10.70 GHz band for protection of the passive earth exploration satellite service (EESS) passive sensors. Originally, the protection was only for 10.68 to 10.7 GHz since it was protected under U.S. footnote 246; however, the 10.6 to 10.68 GHz band also contains the passive sensors and should be protected accordingly.

Coordination is also required in certain instances as shown in Attachment 3. There are various safety-of-life systems below and above 960 MHz that will require the normal NTIA/FCC coordination via the Frequency Assignment Subcommittee process. This coordination will ensure that the UWB imaging systems can be deployed in the area and at the same time, protect any nearby safety-of-life Federal systems.

NTIA has concluded that UWB systems can operate in the spectrum between 0 and 31 GHz as long as the constraints shown in Attachment 3 are adopted. These constraints have been coordinated with the FCC and the major Federal agencies. While these constraints may appear conservative, we believe they reflect the FCC's and NTIA's desire to proceed cautiously in order to protect the incumbent spectrum users, especially those that are providing safety-of-life services, and yet provide spectrum to continue development of the UWB technology.

We look forward to working with you and your staff to continue to provide opportunities for spectrum-dependent technologies.

Sincerely,

William T. Hatch

William T. Hatch
Associate Administrator
Office of Spectrum Management

3 Attachments

# Wednesday, February 13, 2002

## ATTACHMENT 1
## NTIA SUMMARY ANALYSIS OF UWB INTERFERENCE TO GPS AND NON-GPS SYSTEMS

## I. INTRODUCTION

1. This document summarizes a series of measurement and analyses reports undertaken by the National Telecommunications and Information Administration (NTIA) on ultrawideband devices and their affect upon telecommunication systems. NTIA's Institute for Telecommunications Studies in Boulder, Colorado and Office of Spectrum Management in Washington, DC performed these measurements and analyses between the early spring of 1999 and the fall of 2001. NTIA measured several UWB devices to determine their temporal and spatial characteristics and assessed their affects on various receivers and filters to develop a model suitable for predicting interference to general radio communication systems. In addition, NTIA measured the effects of UWB signals on a four Global Positioning System (GPS) receivers in a number of scenarios developed at open meeting held with members of the regulatory community, the UWB community and the GPS community.

2. The models that NTIA developed form these measurements allowed NTIA to develop accurate predictions of the interference effect of UWB transmitters under a number of different proposed operating conditions. These assessments, taken with assessments of the likelihood of the required exposures occurring and the results of similar analyses by others have allowed NTIA to recommend EIRP limits for use when implementing UWB technology.

## II. INTERFERENCE STUDIES

### A. Analyses of UWB Interference to Global Positioning System Receivers

**Measurements**

The NTIA performed measurements on four GPS receivers. Initially, NTIA tested two GPS receivers, a coarse/acquisition (C/A) code tracking receiver architecture that is representative of most GPS applications, and a semi-codeless receiver architecture used for applications that are less dynamic and require more precision such as surveying.[1] In a follow-on measurement effort, NTIA also performed measurements on a GPS receiver employing a narrowly spaced correlator architecture and a Technical Standard Order-C129a (TSO-C129a) aviation compliant GPS receiver also employing the C/A code receiver architecture.[2] The performance criteria used to define and assess interference to receiver operations were: (a) break-lock (BL), a condition that causes a loss of signal lock between the GPS receiver and the satellite, and (b) increase in reacquisition time (RQT), the amount of time it takes a receiver tracking a GPS signal to reacquire the signal after it has been momentarily removed. NTIA also developed a representative set of impulse waveform parameters to characterize the UWB emission environment. The parameters included four PRFs of 0.1, 1, 5, and 20 MHz; four modulation types consisting of constant PRF, On-Off keying, 2% relative reference dither, and 50% absolute dither; and two types of signal gating - 100% and 20%; resulting in 32 permutations. These permutations identified the single source UWB signal structure. An additional set of 5 aggregate signal structures was developed to investigate how several UWB devices acting together would affect the GPS receiver performance.

NTIA performed testing to determine the interference thresholds of the GPS receiver. A GPS simulator was used to establish the GPS receiver operational state. In the test constellation, GPS signals from a four satellite constellation (five satellites were used for the TSO-C129a compliant receiver in order to meet receiver autonomous integrity monitoring requirements) based on ephemeris data taken from an actual GPS constellation present on December 16, 1999. For the measurements performed on the C/A

[1] See NTIA Report 01-384 Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems, February 2001.

[2] See NTIA Report 01-389 Addendum to NTIA Report 01-384: Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems, September 2001.

code, narrowly-spaced correlator, and TSO-C129a receivers the simulator power of the satellite being monitored was set to the minimum specification level of –130 dBm at the GPS receiver input.[3] The simulator power of the satellite being monitored for the semi-codeless receiver was set to –133 dBm at the GPS receiver input. Tracking and acquiring/reacquiring satellites in an open field with no obstructions is relatively straightforward. The challenge comes when there is a partial blockage that reduces the amount of signal energy that reaches the receiver. The key factors that characterize the GPS signal propagation include multipath and blockage from buildings and foliage. These factors reduce the received GPS signal level in urban and suburban areas where GPS receivers are used in land-based applications. The received GPS signal levels from unobstructed satellites can be as much as 7 dB higher, than the guaranteed minimum signal level; however, it is the difficult propagation environment for land-based GPS receiver applications that justifies the use of the minimum signal level in the establishment of regulatory limits.

Conducted measurements were also performed by NTIA to evaluate the interference levels on the GPS receivers, and radiated measurements, using an anechoic chamber to determine whether the GPS antennas altered the UWB radiated signals before they reached the GPS receiver. The results of the radiated measurements confirmed that the GPS antenna does not cause any effects to the portion of the UWB signal within the GPS operating band beyond that of amplifying the signal by the antenna gain in the direction of the UWB device. Outdoor radiated "live sky" measurements, because they cannot be controlled, and cannot be accurately reproduced, are of limited use in establishing regulatory limits. Conducted measurements that are repeatable in a controlled environment are necessary. Moreover, since the ambient noise environment and the contributions from multi-path will change for each geographic location, outdoor, radiated measurements performed in a specific location are of limited use for establishing regulatory limits.

The measurements performed by NTIA also included collecting amplitude probability distribution (APD) statistics, which, together with results from the interference measurements of the GPS receivers, were used to classify the UWB signal interference effects in the GPS receiver into 3 categories; pulse-like, continuous-wave (CW)-like, and noise-like. The pulse-like category was defined by received UWB pulses that were independent,[4] and low duty cycle (low PRF), and could not cause a break-lock condition within the available power of the UWB test generator. The CW-like category was defined by a received UWB interfering signal composed of dominant spectral lines, which produced severe disruption in GPS receiver performance when one spectral line aligned with a C/A code line in the received GPS signal. The noise-like category was defined as UWB spectra without dominant lines and with repeatable measured values for GPS receiver reacquisition thresholds. The UWB signals and GPS noise measured signals were expressed in terms of a 20-MHz bandwidth (centered at 1575.42 MHz), and power measurements were expressed as RMS power levels. The measurements produced values of the RMS power level for interference using BL and RQT thresholds for all of the 32 UWB signal variations and 5 aggregate UWB signal cases.

NTIA's classification of the UWB signals, as they existed in the GPS receivers tested, is similar to classifications for general interference to GPS made by the RTCA (pulsed, CW, and broadband noise) and the ITU-R (CW and broadband noise).[5] The ITU-R and the RTCA have both derived permissible interfering signal limits for each of these classes of GPS interference. For the case of in-band pulsed interference, the RTCA derived limit is a peak power of +20 dBm for pulse widths less than 1 ms and pulse duty cycles less than 10%. For the in-band CW interference case, both the RTCA and the ITU-R interfer-

[3] Global Positioning System Standard Positioning Service Signal Specification, Second Edition, GPS NAVSTAR (June 2, 1995) at pg. 18.

[4] Pulses are independent when the filter bandwidth is greater than the pulse repetition rate. To remain independent the minimum pulse repetition period of a dithered signal must be greater than the duration of the filter impulse response.

[5] NTIA Special Publication 01-45, Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers February 2001 at pg. 2-8.

ence limits are defined as –120.5 dBm for GPS receivers operating in the tracking mode.[6] For in-band broadband noise interference, both the RTCA and the ITU-R limits are -110.5 dBm/MHz for GPS receivers operating in the tracking mode.[7] The NTIA measurement and analysis results are consistent with these values. These RTCA and ITU-R limits are based on a minimum available GPS C/A code signal level of –130 dBm with the GPS receiver antenna gain assumed to be -4.5 dBi.[8] The RTCA and ITU-R interference limits are based on a Minimum Operational Performance Standard for GPS receivers used for Category I/II/III precision approaches.

NTIA measurements demonstrated that if the pulses are relatively short, and produce an impulse response at the output of the filter, and are of a relatively low duty cycle, they will not seriously degrade GPS performance. Further, the interference effect is independent of the pulse amplitude as long as the amplitude is below the receiver peak pulse power limit (approximately +20 dBm). NTIA concluded that GPS performance is relatively robust to pulse-like UWB emissions. The NTIA measurements for the C/A code receiver architecture show that UWB signal with a PRF of 100 kHz causes a low-duty cycle pulse-like interference effect that does not degrade GPS receiver performance. The measurements performed by NTIA for the narrowly spaced correlator and TSO-C-129a receivers, which use the C/A code architecture, also show this low duty cycle, pulse-like interference effect.

The measured susceptibility values, based on the RQT performance criterion, are for a variety of UWB characteristics. The GPS receiver performance criterion for RQT is a "sharp" increase in the average time to reacquire a GPS signal that has been interrupted for ten seconds. This average time was determined by measuring the reacquisition time for each of ten trials (for the same set of test conditions) and then computing the average time of the successful reacquisitions. That is, if the receiver was not able to reacquire within the time allowed for a trial, this trial was not considered in the determination of average reacquisition time. The RQT threshold value was determined by engineering judgment by observing a plot of average reacquisition time and deciding at what UWB input signal level there was a sharp increase in reacquisition time. In general, this sharp increase was more evident for the UWB signals involving higher PRFs (*i.e.*, 5 and 20 MHz) and was more a judgment for the lower PRF conditions.

NTIA also performed measurements of UWB interference to a semi-codeless GPS receiver. Of particular concern for the interference protection of the semi-codeless GPS receiver is the reacquisition data point listed for the UWB signal with a 100 kHz, 2% relative dither and 20% gating. The listed value is -88 dBm/20 MHz. This single value would indicate the semi-codeless receiver is susceptible to low PRF UWB interference. This single value is at least 17 dB lower than the other listed values for a 100 kHz PRF UWB signal. This 17 dB difference includes a 7 dB adjustment to determine the average interference power for the 20% gated signal.

Because this 17 dB difference is significant in determining interference protection requirements, a further review of this data point was carried out. The measured data plots for all the 100 kHz PRF, 20% gated UWB signal cases for the semi-codeless receiver tests were reviewed. This resulted in reviewing four data plots for reacquisition tests from the measured data report.[9] The reacquisition threshold was determined through a judgement as to the power level where a sharp increase in reacquisition time occurred. For three of the data plots, the previous judgement was that no sharp increase was observed over

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[6] ITU-R Recommendation M. 1477, *Technical and Performance Characteristics of Current and Planned Radionavigation-Satellite Service (Space-to-Earth) and Aeronautical Radionavigation Service Receivers to Be Considered in Interference Studies in the Band 1559-1610 MHz* (2000), at Tables 1 and 2. As noted in footnote 2 to these tables, the interference threshold already takes into account the effects of GPS intra-system interference based on random code analysis. This threshold value must account for all other aggregate interference.

[7] *Id.*

[8] Document Number RTCA/DO-229B, Minimum Operational Performance Standard for GPS/Wide Area Augmentation System Airborne Equipment (January, 1996). Recommendation ITU-R M.1477, *supra*, at ANNEX 1, Section 3-2.

[9] NTIA Report 01-384, Figures F.2.5, F.2.9, F.2.17 and F 2.25.

the range of measured interference power levels. Only in the case of concern (100 kHz with 2% relative dither and 20% gating) was a reacquisition threshold selected. In retrospect, because the curves are all similar, a comparative review of the data across the four cases would indicate that a reacquisition threshold should not have been selected over the range of UWB signal powers measured for the 100 kHz PRF, 2% relative dither and 20% gating case. Thus, the entry in Table 2-2 of NTIA Special publication 01-45 should be [-66] rather than -88. The [-66] shows that this was the limit of the power available in the test setup and the effect of interest (the reacquisition threshold) was not observed. This GPS receiver performance, in the presence with low PRF UWB interfering signals, is in agreement with the C/A code receiver architecture results.

For the measurements of the C/A code receiver architecture, NTIA classified 19 of the 32 UWB signal permutations in the pulse-like category. The majority of the PRF values were 100 kHz (8 cases) and 1 MHz (7 cases), however two of the 5 MHz PRF (2% relative and 50% absolute dither with 20% gate), and one 20 MHz PRF (2% relative dither, 20% gate) produced pulse-like interference effects. The NTIA measurements also show that there is a relationship between the interference effect and the receiver bandwidth. For example, some of the UWB signals (particularly among the 1 MHz PRF signals) that produced pulse-like interference effects in the wider band GPS receivers (the 10 MHz C/A code and 16 MHz narrowly-spaced correlator receivers) produced a response characteristic of the more disruptive noise-like or CW-like interference effects in the narrower bandwidth receiver (2 MHz TSO-C129a). As the PRF of the UWB emission increases above 1 MHz, the interference to the GPS receiver can be classified as either noise-like or CW-like. The noise like signal permutations included the 5 and 20 MHz PRF, 100% gated waveform with 2% relative or 50% absolute dithering. Among these four noise-like cases, the worst-case measured interference threshold for the C/A code receiver was –95 dBm/20 MHz (-108 dBm/MHz) corresponding to the 20 MHz PRF, with 50% absolute dithering signal. Nine of the 32 UWB signal permutations were categorized as CW-like. There were four 5 MHz and four 20 MHz PRF cases and one 1 MHz PRF signal set that resulted in CW-like GPS interference effects. Among these 9 CW-like cases, the worst-case interference threshold measured for the C/A code receiver was –99.5 dBm/20 MHz. The adjustments to convert this value to the power level for a single spectral line in a one MHz bandwidth include a 3 dB reduction for the division of power between discrete spectral lines and the continuous spectrum for OOK, a 7 dB reduction to account for the 20% gate-on time relative to total time of 20 msec, and a 7 dB reduction to adjust for a single spectral line that is modulated by a sinc function by the gating period, producing –116.5 dBm.[10] The measured level at which interference occurred to the GPS C/A code receiver was 8 dB less for a CW-like UWB signal than for the noise-like UWB signal. This measured difference is in agreement with the RTCA and ITU-R standards noted above which identify a 10 dB difference for the two interference effects.

**Analysis**

The results of the analysis performed by NTIA are documented in two separate reports: 1) NTIA Special Publication 01-45 that addressed the C/A code and semicodless receiver architectures and 2) NTIA Special Publication 01-47 that addressed the narrowly spaced correlator receiver architecture and a TSO-C129a compliant C/A code receiver.

In order to calculate the maximum allowable EIRP for a UWB device, a source-path-receiver analysis must be performed. The basic parameters that must be defined for this type of analysis are the receiver interference threshold, the source output power and antenna gain, the propagation path between the transmitter and receiver, and the antenna gain of the receiver in the direction of the source transmitter. The data obtained from the measurements performed by NTIA define the interference threshold level at the input of the GPS receiver as a function of UWB signal structure (*e.g.*, power, PRF, modulation scheme) for each of the GPS receiver architectures examined. The UWB device output power and antenna gain combined define the EIRP, which is the variable to be determined from the analysis. In order to make reasonable assumptions regarding the remaining values needed for the analysis, information re-

[10] NTIA Special Publication 01-45, *supra*, at pg. 2-12.

garding how the transmitter and receiver can interact within their operating environment is necessary. Collectively, this information defines an operational scenario, which establishes how close the two systems may come to one another under actual operating conditions, and the likely orientation of the antennas. This information is then used to compute the propagation loss and the receive antenna gain in the direction of the transmitter. The operational scenario can also be used to determine the applicability of factors such as building attenuation, multiple transmitters, and safety margins.

In order to develop representative scenarios to analyze, NTIA hosted a series of open public meetings to develop operational scenarios to be considered. The meetings were announced in the *Federal Register* and participation was encouraged within the UWB and GPS communities and among the interested Federal agencies. Specific proposals for operational scenarios to be considered included GPS receivers used in the following applications: land-based (*e.g.*, public safety, emergency response vehicle navigation, geographic information systems, precision machine control); maritime navigation (in constricted waterways, harbors, docking, and lock operations); railway operations (positive train control); surveying; and aviation (en-route navigation and non-precision approach). The input received at the public meetings was used to develop the operational scenarios considered in the NTIA analysis.

There are two operational scenarios proposed on the record, however, that will serve as the limiting scenarios for establishing the emission limits for UWB devices operating indoors: 1) the land-based multiple UWB device operational scenario developed by NTIA and 2) the E-911 operational scenario. The following paragraphs will provide a detailed discussion of these operational scenarios.

The first limiting operational scenario for the indoor use of UWB devices is where there are several UWB devices operating inside of a building and the GPS receiver is operating outdoors. The following table provides an overview of the technical factors for noise-like interfering UWB signals considered in the analysis for this operational scenario.

**Table 1 Technical Factors Considered for Indoor UWB Interference to GPS**

| Parameter | Value | Value |
|---|---|---|
| GPS Receiver Interference Susceptibility (dBm/MHz) (Performance Metric) | -102.5 (BL) | -108 (RQT) |
| Propagation Loss (dB) (Minimum Distance Separation (m)) | 55 (8.6) | 55 (8.6) |
| GPS Receive Antenna Gain (dBi) | -3 | -3 |
| UWB Device Interference Allotment (dB) (Percentage UWB) | -3 (50) | -3 (50) |
| Allotment for Multiple UWB Devices (dB) (Number of Devices) | -6 (4) | -6 (4) |
| Manufacturer Variation (dB) | -3 | -3 |
| Average Building Attenuation (dB) | 9 | 9 |
| Allowance for Acquisition (dB) | -6 | 0 |
| Maximum Allowable EIRP (dBm/MHz) | -59.5 | -59 |
| 47 C.F.R.§15.209 Emission Limit (dBm/MHz) | -41.3 | -41.3 |
| Additional Attenuation Required (dB) | 18.2 | 17.7 |

The UWB emission limit recommended in the above table is calculated by adding the values in the columns. As shown in the table, for noise-like UWB signals an additional 18 dB of attenuation below the 47 C.F.R.§15.209 emission limit is necessary to protect the GPS receiver under the conditions in this operational scenario. The following paragraphs will provide a detailed discussion of each of the technical factors considered in this operational scenario.

The GPS interference susceptibility levels used in this analysis correspond to the break-lock and reacquisition performance metrics of the GPS receiver. As discussed earlier, the GPS receiver interference susceptibility referenced to the input of the receiver was obtained from the single source measurements performed by NTIA. The values used in this analysis are based on the UWB signal structure that causes the most susceptible noise-like interference threshold that was measured by NTIA.

The propagation loss is computed using the minimum distance separation between the GPS receiver and the UWB device as defined by the operational scenario considered. For this operational scenario the minimum distance separation is computed from the slant range with the GPS receiver located 5 meters from the building and the UWB device 7 meters above the GPS receiver. The computed minimum distance separation is 8.6 meters. A factor for loss due to vegetation may be applicable in other operational scenarios, however, it is not appropriate in this case, and will not be included in the analysis. Scattering loss that would result from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls could also be included. Signal scattering similar to the effects of multi-path are difficult to predict and are highly dependent on the surrounding obstacles. Since there is no way to accurately predict the types of obstacles that exist in a given area, the inclusion of such a factor in this analysis is not appropriate.

The UWB devices, which are indoors, in this operational scenario, are located above the GPS receiver, which is outside. The antenna model used by NTIA for the GPS receiver indicates that the receive antenna gain is 3 dBi. The antenna for the UWB device is assumed to be omni-directional. It is envisioned that most mobile/handheld UWB device applications will employ omni-directional antennas that will provide essentially uniform coverage in the horizontal direction and in the vertical direction for low elevation angles. When considering interference under a general operational scenario, it would not be appropriate to include an off-axis antenna alignment factor in the analysis of this operational scenario, where omni-directional antennas are likely to be employed. Off-axis discrimination is typically employed when analyzing stations in the fixed radio service, for example, where the locations of the transmitters and antenna pointing angles are known. Since the locations, the types of antennas being employed, and the antenna pointing angles of the UWB devices are all unknowns; it is inappropriate to include a factor for off-axis antenna alignment in this analysis. An off-axis antenna alignment factor could be applied in an operational scenario examining aggregate interference to an airborne receiver from a large number of land-based UWB devices, such as in an en-route navigation operational scenario. However, it is not appropriate to include such a factor in the analysis of this operational scenario.

Polarization mismatch loss, also referred to as polarization discrimination or polarization isolation, is the ratio at a receiving point between received power in the expected polarization and received power in a polarization orthogonal to it from a wave transmitted with a different polarization. Polarization mismatch is a common technique used in sharing the same frequency for fixed point-to-point microwave systems and fixed satellite earth stations. The key factor being that the transmitter and receiver antennas are fixed and their polarization are known. Moreover, the polarization of an antenna remains relatively constant throughout the main lobe of the antenna pattern, but varies considerably in the minor lobes.[11] In practice, polarization of the radiated energy varies with the direction from the center of the antenna, such that different parts of the antenna pattern and different sidelobes have different polarizations.[12] This is also true for GPS antennas where in the mainbeam the polarization is circular, but outside the mainbeam in the lower elevation angles the polarization is nearly linear. Since the locations of the UWB devices, and polarizations are unknown we do not believe that a factor for polarization mismatch loss should be included in the analysis.

In addition to the potential interference from UWB devices, several other potential sources of interference to GPS receivers have been identified. These potential sources of interference include but are not limited to: 1) adjacent band interference from mobile-satellite service Mobile Earth Terminals (METs); 2) harmonics from television transmitters; 3) spurious emissions from 700 MHz public safety base, mobile, and portable transmitters; and 4) spurious emissions including harmonics from 700 MHz commercial

[11] Antenna Engineering Handbook, R.C. Johnson, H. Jasik (Second Edition) at pg. 1-7.

[12] Antenna Analysis, E.A. Wolff (1966) at pg. 17

base, mobile, and portable transmitters. Multiple sources of interference, which might individually be tolerated by a GPS receiver, may combine to create an aggregate interference level that could prevent the reliable reception of the GPS signal. The emission limits of the MSS METs, 700 MHz public safety and commercial transmitters is –70 dBW/MHz for noise-like interference. The zone of interference of each of these transmitters could be as much as a circle of 30-meter (100-foot) radius, if it emits out-of-band radiation at the limit. The harmonic emission from digital television (DTV) transmitters is –110 dBc and will result in a zone of interference that is as much as a circle of 270 meters (884-foot) radius. As a consequence these transmitters do not have to be located next to a GPS receiver to disrupt signal reception in land-based applications. In this operational scenario one half of the total allowable interference budget is allotted to UWB devices and the other half is allotted to all other interfering sources combined. The factor for UWB device interference allotment is computed from 10 Log (UWB interference allotment ratio). For a UWB device interference allotment of 50% (a ratio of 0.5), a 3 dB factor is included in this analysis. The use of allotments for multiple sources of interference is not a new concept in studies examining interference from one radio service to another. For example, ITU-R Recommendation F.1094-1 specifies an interference allotment of 89% for transmitters of the same radio service, an interference allotment of 10% for radio transmitters in other radio services, and a 1% interference allotment for all other sources (*e.g.*, unlicensed transmitters).[13] This is also consistent with ITU-R Recommendation M.1477, which states that when there is a potential for more than one source of interference at the same time, it will be necessary to apportion the interference threshold among the potential interference sources.[14] Since the GPS/UWB measurements that are part of the public record in this proceeding did not include other potential sources of interference, it is appropriate to include a factor in the analysis to take them into account.

The factor for multiple UWB devices was obtained from the multiple source (aggregate) measurements performed by NTIA. The measurements performed by NTIA verified that if the individual signals cause an interference effect that is noise-like, the interference effect of the multiple noise-like signals is noise-like. Based on the measurements, for UWB signal permutations that have been characterized as causing noise-like interference, a factor of 10 Log (number of UWB devices) is included in the analysis for emitters that are at the same distance from the GPS receiver. The inclusion of an activity factor is appropriate when there are a large number of UWB devices considered in the operational scenario. The activity factor is also dependent upon the UWB application. Since there are only four UWB devices in this operational scenario and it is not possible to accurately estimate representative values of activity factors, we will not use an activity factor in this analysis (*i.e.*, the UWB devices will be continuously transmitting).

A 2001 GPS Receiver Survey lists 64 different manufacturers of GPS receivers.[15] The survey lists approximately 500 different models of GPS receivers representing the C/A code, semi-codeless, and narrowly spaced correlator receiver architectures. The NTIA measurements included one receiver from each of the three GPS architectures. Based on the NTIA measurements and the results of the other measurement efforts that are part of the public record in this proceeding, initial engineering modeling of the interference effects of UWB signals on the different GPS receiver architectures has emerged. However, the number of different models of GPS receivers and manufacturers considered in the current measurement efforts may not completely represent the performance of all the GPS receivers currently being manufactured. There may be differences in hardware, firmware,[16] or software (*e.g.*, tracking and acquisition algorithms) employed in the receivers that were not considered in the current measurement efforts. There may be differences in the models produced by the same manufacturer as well as between receivers produced by different manufacturers. Therefore, the inclusion of a factor in the analysis to account for these

[13] ITU-R Recommendation F.1094-1, Maximum Allowable Error Performance and Availability Degradations to Digital Radio-Relay Systems Arising from Interference from Emissions and Radiations from Other Sources.

[14] ITU-R M.1477 at Annex 5.

[15] *GPS World Receiver Survey*, GPS World Magazine, January 2001, at pg. 32.

[16] Firmware is software installed in a device that is typically stored in read only memory (ROM) or programmable read only memory (PROM).

possible differences is reasonable. Based on an analysis performed by NTIA of the data that is on the public record in this proceeding, the range of data indicates that the more susceptible interference thresholds are within 3 dB of the median.[17] The NTIA analysis included this factor to take into account the small number of GPS receivers considered in all of the measurement efforts. The analysis performed by the Johns Hopkins University/Applied Physics Laboratory (JHU/APL) also acknowledged that there are differences in GPS receivers. Specifically JHU/APL concluded that variations in the measurements of performance due to different GPS receivers are greater than those due to the operating modes of the UWB tested devices. JHU/APL further concluded that the impact of UWB devices on all GPS receivers could not be assessed using a single GPS receiver.[18] Based on the analysis performed by NTIA and the conclusions reached in the JHU/APL analysis, a value of 3 dB is used in this analysis for manufacturer variation.

As part of a separate measurement effort, NTIA has conducted building attenuation loss measurements at 912, 1920, and 5990 MHz.[19] The measurements were performed for different buildings representing typical residential and high-rise office construction. Based on the results of these measurements, an average building attenuation of 9 dB in the range 960-1610 MHz in which GPS operates is used in this analysis. The standard deviation for the measurements, however, is on the same order of magnitude as the value of building attenuation loss.[20]

The NTIA measurements did not consider the acquisition of a new satellite in the presence of a UWB signal. The acquisition threshold is known to be more sensitive than the tracking threshold, which can, in part, be attributed to the time and frequency search performed by the GPS receiver as part of the satellite acquisition scheme. As part of the satellite acquisition process, the loop filter bandwidths are increased, which causes the noise (N) to increase reducing the effective carrier-to-noise ratio (C/N). The acquisition mode of the GPS receiver is extremely difficult to measure, because it is highly dependent on manufacturer-specific acquisition algorithms. A 6 dB factor is typically used in GPS interference analyses to account for the greater sensitivity of satellite acquisition.[21] This 6 dB reduction in the interfering signal power level only, provides protection of 2.5 dB in C/N+I, which is a critical factor in GPS receiver performance. Since the performance metric of break-lock is related to the tracking performance of the GPS receiver, including the acquisition factor in the analysis when the interference susceptibility is based on the break-lock performance is appropriate.

The second limiting operational scenario to be considered for UWB devices restricted to indoor use is the indoor use of E-911 GPS receivers. Because buildings and other structures attenuate the received GPS satellite signals, indoor reception has not been possible previously. However, Global Locate and Snap Track (Qualcomm) have developed technologies that permit indoor, enhanced GPS reception for E-911 applications. These technologies rely on enhancing the signal processing of the E-911 received GPS signal with information provided from a separate GPS receiver located at the base station. This supplemental information provides Doppler and code shift data to allow acquisition and tracking of low level GPS signals. In addition, information involving phase shifts caused by the GPS navigation signal is provided to allow coherent integration of the E-911 GPS signal for a period longer than 20 msec. The enhanced GPS receiver integrates the satellite signal over a longer time period, allowing the receiver to obtain a 20 to 30 dB higher processing gain than a conventional GPS receiver.[22] This higher processing

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[17] *See* NTIA Special Publication 01-47, Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers (Report Addendum), November 2001.at pg. 2-13.

[18] JHU/APL Report at ES-2.

[19] NTIA Report 95-325, Building Attenuation Measurements From Low-height Base Stations at 912, 1920, and 5990 MHz, September 1995, at pg. 43.

[20] *Id.* at pg. 36.

[21] *Understanding GPS Principles and Applications*, E. D. Kaplan (Editor), Artech House, 1996, pg. 211; ITU-R M.1477 at Annex 1

[22] Note that these are only estimates of what values of processing gain can be achieved and may vary depending on the implementation of the technology.

gain permits the reception of a GPS signal that is significantly below the receiver noise floor in a 1 MHz bandwidth.

This processing, to determine location of the E-911 receiver, can be carried out at the E-911 receiver using supplemental data from the base station that is provided via the phone connection. An alternative is to do the final processing at the base station. For example, a snapshot (in time) of the signals (in the GPS band) received at the E-911 receiver is forwarded to the base station via the phone connection where the signal and supplemental information is processed to determine location of the E-911 receiver. These processing technologies require that the E-911 receiver is not on a platform that is moving rapidly. Significant motion could, for example, invalidate the supplemental Doppler information and/or invalidate the final position solution, which involves some time latency due to the signal processing procedure. At this time, it is expected that the E-911 position determination would not be invoked until the emergency (911) call is placed.

Regardless of the processing gain or the bandwidth of the tracking loop, the minimum level of the GPS signal that can be used for an E-911 position determination will be determined by the receiver system noise density. An interfering signal that adds to the system noise density will necessitate a higher GPS signal level thus decreasing the indoor coverage of the E-911 position determination capability. Thus, we believe that an analysis of an indoor UWB transmitter and an E-911 GPS receiver provides the more stringent interference example. The following table provides an overview of the technical factors considered in the analysis for this operational scenario.[23]

**Table 2 Analysis of UWB Indoor Interference to E-911 Indoor System.**

| Parameter | Value |
|---|---|
| Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise) | -117.5 |
| GPS Antenna Gain in Direction of RFI Source (dBi) | 0 |
| Propagation Loss (dB) (Minimum Distance Separation (meters)) | 42.4 (2) |
| **Noise-Like RFI Emission Limit (dBm/MHz)** | **-75.1** |
| 47 C.F.R.§15.209 Emission Limit (dBm/MHz) | -41.3 |
| **Additional Attenuation Required (dB)** | **33.8** |

The UWB emission limit recommended in the above table is calculated by adding the values in the columns. As shown in the table, for noise-like interference, UWB signals must be 31 dB below the 47 C.F.R.§15.209 emission limit to protect the GPS receiver under the conditions in this operational scenario. The following paragraphs will discuss each of the technical factors considered in this operational scenario.

The typical receiver system noise density of a GPS receiver is –171.5 dBm/Hz for a 3 dB receiver noise figure.[24] An interference susceptibility value of an I/N of 0 dB would result in a 3 dB increase in the system noise density. This means that interference at this level can cause a 100% increase in the GPS receiver system noise density. As stated earlier, the receiver system noise density determines the minimum level of the GPS signal that can be used for an E-911 position determination. Therefore, an interfering signal that adds to the system noise density will limit the GPS signal level that can be tracked by the receiver. Conventional GPS receivers require a relatively high $C/N_0$ because of the wide loop bandwidths that are employed. In contrast GPS receivers used in E-911 applications can take full advantage of

[23] This operational scenario would be applicable to any application where an appropriate data link can be established between a base station and a GPS equipped handset.

[24] The noise figure of a GPS receiver typically is in the range of 2 to 4 dB.

communication network support to obtain and remove the GPS navigation data and to stabilize the receiver clock. In addition, it is assumed that the dynamics are very low (e.g., the user is walking). As a result, the tracking bandwidth can be narrowed very substantially, thus maintaining a positive signal-to-noise ratio in the tracking loop at much lower $C/N_0$ values. Receivers are being designed today which can track with a 20 dB $C/N_0$, and the industry is striving to track with a $C/N_0$ of 10 dB. Based on the system noise density of –171 dBm/Hz, a 20 dB $C/N_0$ represents a received signal level of –151 dBm, and a 10 dB $C/N_0$ represents a received signal level of –161 dBm. There are GPS receivers that exist today that are capable of tracking signals that are 21 dB weaker than the signal levels considered in the measurement efforts that are part of the public record in this proceeding. If improvements permit tracking at a $C/N_0$ of 10 dB, the tracked signal level would be 31 dB weaker than the signal levels considered in the measurement efforts. Based on the lower received signal levels that can be tracked by GPS receivers, a 100% increase in the system noise is not acceptable. Limiting the increase in system noise caused by noise-like UWB signals to 50%, equates to an interference susceptibility level of –114.5 dBm/MHz. The GPS Joint Program Office has recommended that the sensitivity should be degraded by no more that 1 dB (25% increase in the system noise density). For a 1 dB increase in the system noise density, the I/N is –6 dB. Based on an I/N of –6 dB the interference susceptibility level used in this analysis is –117 dBm/MHz.

Based on the typical antenna model specified in the NTIA analysis, the antenna gain of 0 dBi in the direction of the UWB device is appropriate and will be used in this analysis. Also for a 2 meter (6.6 feet) distance separation the use of the free space propagation model to compute the propagation loss is appropriate.

As shown in the table above, for noise-like interference, UWB signals must be 34 dB below the 47 C.F.R.§15.209 emission limit to protect the GPS receiver in this operational scenario.

Based on the above analysis, of the two limiting operational scenarios for the indoor use of UWB devices, we conclude that a UWB signal level 34 dB below the Part 15 general emission limits is required for noise-like UWB emissions in the 960-1610 MHz range. This attenuation will be required for all indoor UWB systems.

Imaging systems, vehicular radar systems, and hand-held systems will be permitted to operate outdoors, provided the emissions in the GPS bands are below the Part 15 general emission limit. The limiting operational scenario considered for the outdoor use of GPS and imaging systems is given in the table below.

**Table 3 Outdoor Analysis for Imaging System Interference to GPS**

| Parameter | Value |
|---|---|
| GPS Receiver Interference Susceptibility (dBm/MHz) (Broadband Noise) | -117.5 |
| Propagation Loss (dB) (Minimum Distance Separation (m)) | 52 (6 m) |
| GPS Receive Antenna Gain (dBi) | 0 |
| **Maximum Allowable EIRP (dBm/MHz)** | **-65.5** |
| 47 C.F.R. §15.209 Emission Limit (dBm/MHz) | -41.3 |
| **Additional Attenuation Required (dB)** | **24.2** |

As shown in the table above, a signal level 24 dB below the Part 15 general emission limit is required for noise-like emissions in the 960-1610 MHz frequency range from imaging systems. We also believe that imaging systems typically will emit RF energy only for short periods of time, so any possible interference from operation at closer distance separations should be transient.

The limiting operational scenario considered for the outdoor use of GPS and vehicular radar systems is given in the table below.

**Table 4 Analysis for Vehicular Radar System Interference to GPS Receivers**

| Parameter | Value |
|---|---|
| Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise) | -117.5 |
| GPS Antenna Gain in the Direction of UWB Device (dBi) | 4.5 |
| Propagation Loss (dB) (Minimum Distance Separation (meters)) | 48.4 (4) |
| Allotment for Multiple UWB devices (dB) | -10 |
| **Noise-Like Emission Limit (dBm/MHz)** | **-74.6** |
| 47 C.F.R. § 15.209 Emission Limit (dBm/MHz) | -41.3 |
| **Additional Attenuation Required (dB)** | **33.3** |

The typical implementation of the vehicular radar systems will consist of multiple radar systems (as many as 8 to 12 per vehicle) that are mounted on the bumpers and fenders of the vehicle. Vehicular radar systems will also employ directional antennas and will be installed at a height of approximately 0.5 meters.[25] Based on anticipated operational use of vehicular radar systems the antenna discrimination of a GPS antenna in the direction of the vehicular radar systems and interference from multiple vehicular radar systems must be considered in the analysis.

Since the vehicular radar systems are mounted at a height of approximately 0.5 meters they will typically be below the GPS antenna. Based on the antenna model provided by NTIA, the GPS receive antenna gain in the direction of the vehicular radar systems would be –4.5 dBi.

In order to determine the location of vehicles and objects that surround the vehicle multiple vehicular radar systems employing directional antennas will be employed. In this analysis it will be assumed that there are eight vehicular radar systems transmitting in the direction of the GPS receiver and a factor of 10 Log (10) or 10 dB will be included in the analysis.

As shown in Table 4, a signal level 33 dB below the Part 15 general emission limit is required for noise-like emissions from vehicular radar systems in the 960-1610 MHz frequency range.

The limiting operational scenario considered for the outdoor use of GPS and hand-held systems is given in the table below.

**Table 5 Analysis of UWB Indoor Interference to E-911 Indoor System.**

| Parameter | Value |
|---|---|
| Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise) | -117.5 |
| GPS Antenna Gain in Direction of RFI Source (dBi) | 0 |
| Propagation Loss (dB) (Minimum Distance Separation (meters)) | 42.4 (2) |
| **Noise-Like RFI Emission Limit (dBm/MHz)** | **-75.1** |
| 47 C.F.R.§15.209 Emission Limit (dBm/MHz) | -41.3 |
| **Additional Attenuation Required (dB)** | **33.8** |

[25] BOSCH presentation to European Ultra Wideband Workshop, *Short Range Automotive Radar (SRR) ... another generic (ultra) wide band device at 24 GHz* (March 20, 2001) at. pg. 4.

As shown in Table 5, a signal level 34 dB below the Part 15 general emission limit is required for noise-like emissions from vehicular radar systems in the 960-1610 MHz frequency range.

## B. Analyses of UWB Interference to Various U.S. Government Systems

NTIA analyzed the interactions between UWB transmitters and a number of U.S. Government radio communication systems to determine, *inter alia,* the maximum UWB emission levels that could be allowed without causing interference. These analyses were based on an extensive laboratory measurement program at the Institute for Telecommunication Sciences, in Boulder, CO. The measurement program identified various methods being currently used to generate UWB signals and characterized the essential parameters of UWB systems provided by various UWB manufacturers. The ITS verified how filters of varying bandwidths respond to numerous types of UWB signals and determined measurement techniques that correctly measure the emission spectra of UWB devices. The ITS also performed a measurement program to determine the nature of the aggregation of UWB signals.[26] NTIA also initiated a measurement program consisting of field measurements of radiated UWB signals at the FAA Aeronautical Center in Oklahoma City, OK to determine the effects of one UWB device operating at the current Part 15 limits on an Air Route Surveillance Radars (ARSR), and Airport Surveillance Radars (ASR) in order to validate the prediction models used in the analysis. In its reports, NTIA provided quantitative values for UWB emission limits involving federal systems for the following: RMS power limits for a UWB device located at 2 m and at 30 m above the ground for 15 systems (and peak power limits for two of the systems); and developed a computer model for assessing the impact of aggregate UWB interference. The NTIA interference analyses of the effects of RMS and peak power were based on a link budget equation involving the system threshold for interference, as determined using standard established interference protection criteria, actual antenna elevation gain patterns for the victim receivers, the Irregular Terrain Model for propagation loss, estimated system losses, and the empirically determined correction factors for bandwidth to determine the UWB limits in power per megahertz (dBm/MHz).

The NTIA analysis was performed for 7 UWB PRFs ranging from 1 kHz to 500 MHz for both dithered and undithered signals. The NTIA study used the current Part 15 limit, an RMS EIRP of -41.3 dBm/MHz at frequencies above 1 GHz, as the baseline for the study. The study determined the allowable UWB emission levels and did not specifically address the 12 dB reduction from the current Part 15 level in the bands below 2 GHz as proposed in the *Notice*. The analysis also assumed that the UWB devices were located out of doors. The following is a summary of the NTIA's report for non-GPS systems.

[26] *See* NTIA Special Publication 01-43, *supra*, and NTIA Report 01-384, *supra.*

**Table 6 Maximum UWB EIRP for Outdoor Use of UWB at 2m & 30 m**

| System | Freq (MHz) | Max UWB EIRP (dBm/MHz) (UWB Outdoors 2 m) | Max UWB EIRP (dBm/MHz) (UWB Outdoors 30 m) |
|---|---|---|---|
| DME, Interrogator | 960-1215 | -47 | Not Applicable |
| DME, Transponder | 1025-1150 | -64 | -56 |
| ATCRBS, Transponder | 1030 | -44 | Not Applicable |
| ATCRBS, Interrogator | 1090 | -31 | -45 |
| ARSR-4 | 1240-1370 | -61 | -82 |
| SARSAT | 1544-1545 | -69 | -66 |
| ASR-9 | 2700-2900 | -46 | -66 |
| NEXRAD | 2700-2900 | -42 | -76 |
| Marine Radar | 2900-3100 | -56 | -57 |
| FSS, 20 degrees | 3700-4200 | -36 | -42 |
| FSS, 5 degrees | 3700-4200 | -51 | -77 |
| CW Altimeters | 4200-4400 | 25 | Not Applicable |
| Pulsed Altimeter | 4200-4400 | 14 | Not Applicable |
| MLS | 5030-5091 | -54 | Not Applicable |
| TDWR | 5600-5650 | -35 | -63 |

NTIA investigated the potential interactions of proposed UWB systems on 15 U.S. Government systems operating between the frequencies of 960 and 5650 MHz. The systems investigated included Distance Measuring Equipment (DME) interrogator airborne receiver, DME ground transponder receiver, Air Traffic Control Radio Beacon System (ATCRBS) air transponder receiver, ATCRBS ground interrogator receiver, ARSR), Search and Rescue Satellite (SARSAT) ground station land user terminal, ASR, Next Generation Weather Radar (NEXRAD), Maritime Radar, Fixed Satellite Service (FSS) earth stations, CW and Pulsed Radar Altimeters, Microwave Landing Systems (MLS), and Terminal Doppler Weather Radar (TDWR). Table 1 denotes these systems and their frequency band of operation and summarizes NTIA's conclusions of emission limits necessary to preclude interference from a UWB transmitter operating at a height of 2 or 30 meters. The maximum UWB EIRP is the maximum signal level that NTIA calculated at which a UWB transmitter could operate without causing interference to the system when the UWB is allowed unrestricted outdoor operation independent of the UWB's pulsewidth, PRF, or other modulation schemes or the nature of it's intended operation (e.g. radio determination or communication). Where there was a difference due to the PRF of the UWB emission, we have included the results from the PRF that required the UWB emissions to be reduced to the lowest level. In the column for 30 meters, "Not Applicable" indicates that the particular scenario would involve a UWB transmitter on a fixed antenna tower at the same altitude as the airborne victim, which would not be likely.

The protection criteria for most of the systems were determined from International Civil Aeronautical Organization (ICAO), RTCA and ITU-R standards developed from system spectrum sharing criteria. The protection levels for the DME interrogator, the ATCRBS systems, and the MLS were based, however, on specific system performance specifications and additional protection margins recommended by the FAA's Spectrum Management and Policy Program Division. NTIA chose to use international and national sharing and coordination criteria partly because harmful interference is a subjective criterion. Moreover, there are well-established critical operations, many involving safety of life situations and therefore, it is appropriate to provide them protection from interference rather than ensure that harmful interference is unlikely. The following discussion examines these protection criteria for each of the examined systems.

**DME, Interrogator**. This system is used to provide civil and military aircraft pilots with the distance from a specific ground beacon, the transponder, for navigational purposes. In Appendix A of its report, NTIA referenced the RTCA specification[27] for a 70 percent reply efficiency at a –83 dBm receiver sensitivity, and calculated that the interference threshold should be set at –115 dBm, which is an I/N of -7 dB as shown by Table A-9. [28] For all conditions studied and proposed, a UWB EIRP of –47 dBm is adequate to protect the operations of the DME interrogator receiver.

**DME, Transponder**. This device responds to interrogations from the DME airborne component. NTIA applied a 10 dB UWB partitioning and 6 dB aeronautical safety margin directly to the –106 dBm receiver thermal noise level calculating that the interference threshold should be–122 dBm. The initial study of the DME transponder showed that an EIRP of –64 dBm was necessary to protect its operations from UWB operations with the additional caveat that no UWB could come as close as 15 meters. The analysis also showed that an EIPR of –41.3 dBm would be adequate to protect the transponder, however, it would be necessary to ensure that UWBs not operate any closer than 260 meters, which cannot be guaranteed. The operational limits required for the protection of the GPS will also be adequate to protect DME operations.

27 *Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960-1215 MHz*, RTCA DO-189, at 2.2.11 (September 1985).

28 NTIA Special Publication 01-43, *supra*, at page A-19, Table A-9.

**ATCRBS Transponder and Interrogator**. These systems are used in conjunction with the ASR and ARSR and other air traffic control radars to provide controllers with the location, altitude, and identity of civil and military aircraft through an interrogate and reply operation. The protection criteria employed by NTIA were based on the minimum triggering levels, that is the minimum input power levels supplied to the sensor RF port that results in a 90 percent reply ratio for the transponder, -77 dBm, and a 90 percent reply ratio for the interrogator, -79 dBm. Both the interrogator and the transponder must be able to demodulate and decode 90 percent of the interrogations (replies) with a S/I of 12 dB.[29] NTIA used the power level for 90 percent reply detection as the system threshold and applied the RTCA and FAA 12 dB S/I criterion to these values to determine the interference thresholds. NTIA's final system interference thresholds are 11 dB above the receiver thermal noise floor for the interrogator system and 9 dB above the receiver noise floor for the transponder system. ATCRBS transponder and interrogator operations will be protected due to limits imposed by other systems (*e.g.*, DME, ARSR-4, and GPS).

**ARSR-4**. This system is used by the FAA and DOD to monitor aircraft during enroute flight to distances of beyond 465 km (250 nm). NTIA used a protection criterion of an Interference to thermal Noise ratio of -10 dB, *i.e.*, I/N = -10 dB, while the current protection criteria in ITU-R Recommendation M.1463 is for an I/N of –6 dB for both radionavigation and radiolocation applications of radar.[30] Low PRF operations of UWB devices, even near ground level, must be limited to -61 dBm EIRP to protect the ARSR-4. The high gain of the ARSR-4 antenna, and its low "look angle" preclude allowing higher UWB EIRP levels. EIRP levels of –41.3 dBm, as predicted in the analysis, and verified by NTIA's measurements, will severely reduce the minimum discernable signal, even at distances of more than 5 kilometers. However, the operational limits required for the protection of the GPS will be adequate to protect ARSR-4 operations.

**SARSAT-LUT**. This system provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress. NTIA used a protection criterion of I/N = -9 dB. The NTIA SARSAT-LUT analysis was based on the SARSAT receive antenna operating at an elevation angle of 0 degrees, *i.e.*, the receive antenna is pointed directly at the horizon. At this elevation angle, the large gain of the antenna amplifies emissions from a UWB device at 2 m height. Although, both TDC and XSI stated the performance specification for SARSAT dictates acquiring the satellite when it reaches an elevation angle of 5° above the horizon, not at 0°, the acquisition process begins at, or near 0° elevation.[31] At an elevation angle of 5°above the horizon, there is 10 dB less gain provided by the SARSAT-LUT antenna. Although TDC and XSI are correct in their observations, the SARSAT-LUT antenna is scanned to that low of an elevation angle specifically to quickly acquire the COSPAS/SARSAT satellites as they appear on the horizon. Thus use of the maximum antenna gain is appropriate. Of the UWB operations proposed, outdoors use will have the greatest potential to interfere with SARSAT operations. GPS protection levels, which are more than adequate to protect the SAR-

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29 *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/MODE S) Airborne Equipment*, Radio Technical Commission for Aeronautics, RTCA DO-181A, at 2.2.8.1 (January 1992) and Federal Aviation Administration, US Department of Transportation, *Specification for Mode Select Beacon System (Modes) Sensor*, Amendment 2, FAA-E-2716 (March 1993).

30 An I/N of –6 dB translates to an increase in the noise floor of 1 dB and a reduction in the maximum radar range of just under 6 percent. A value of –10 dB translates to an increase in the noise floor of about 0.5 dB and a reduction in the maximum radar range of just under 3 percent

31 TDC comments of 3/12/01 at pg. 10, footnote 18. XSI comments of 3/12/01 at pg. 7. *See COSPAS-SARSAT LEOLUT Performance Specifications and Design Guidelines*, Document C/S T.002, Issue 3, Rev. 1 (Oct. 1999) in Section 3.5 at 3-1. This states that the LUT shall be able to track the LEO SARSATs when they reach 5 degrees above the horizon.

SAT terminals, will limit indoor and vehicular use of UWB. The necessity for use of imaging or ground penetrating radar should be minimal at the seven SARSAT locations, and assure yet further protection.

**ASR-9**. This radar monitors the location of civil and military aircraft in and around airports to a range of 110 km (60 nm). NTIA stated that the protection criterion for this radar was an I/N of –10 dB. The U.S. Submission to ITU-R Working Party 8B proposed this level in a revision to ITU-R M.1464, which is under consideration by ITU-R Study Group 8 and is an official US position. There is also a proposal by Working Party 8B to decrease the I/N to –12 dB involving an evaluation of expected interference to radars from systems using Orthogonal Frequency Division Multiplex (OFDM) modulation methods. The proposal to change the I/N to –12 dB also includes noise like interference sources, and is not solely based on an OFDM type interferer.[32] However, the –10 dB level is the agreed upon U.S. position with the ITU and is appropriate for this analysis. In calculating the required emission limits for UWB devices to protect the ASR-9, NTIA used average antenna heights and antenna tilt angles. Only indoor UWB operation in a 30 m building exceeds the predicted protection limit for the ASR-9. The ASR-9 requires a limitation of the EIRPs of UWBs operating inside buildings to -57 dBm, while the proposed limit for indoor UWBs in this band is –51.3 dBm. Further calculations show that if the protection level is –51.3 dBm, the required separation distance for a UWB operating at this EIRP level is 270 meters. This 3.7 dB difference effectively would reduce the I/N from –10 to –6 for this system and would increase the noise floor by 1 dB instead of ½ dB. While this would diminish the capabilities of this radar in same the azimuth of the building, it is not as severe a problem as the reduction of the coverage in this azimuth due to the physical line-of-sight blockage caused by a 10-story building within 270 meters of an ASR-9.

**NEXRAD**. This radar provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information. NTIA refers to ITU-R M.1464, the same specification called out for the ASR-9 but uses a level of –6 dB below the noise floor as the applicable protection level since the NEXRAD radar is used for meteorological purposes. Only indoor UWB operation in a 30 m building in a 30 m building less than 760 meters away exceeds the predicted protection limit for the NEXRAD. The NEXRAD requires a limitation of the EIRPs of UWBs operating inside buildings to -67 dBm, while the proposed limit for indoor UWBs in this band is –51.3 dBm. Given the 0.5-degree minimum elevation angle of the antenna mainbeam, the beam would only be 6.6 meters above the ground at 270 meters. The building itself would at least partially obstruct the 3 dB beam width of the mainbeam and be the limiting factor along the given azimuth and not the UWB's EIRP. An elevation angle of greater than 2 degrees is required to clear a 30-meter obstacle at a distance of 270 meters.

**Marine Radionavigation Radar**. These S-band radars provide information on surface craft locations, obstructions, buoy markers, and navigation marks, *e.g.*, shore-based beacons and radar beacons to assist in navigation and collision avoidance. NTIA employed an I/N protection criterion of –10 dB indicating that this level is contained in a proposed revision to ITU-R M.1313-1 under consideration by ITU-R Study Group 8 and entitled, *Technical Characteristics of Maritime Radionavigation Radars.* The outdoor level to protect the maritime radar is –56 dBm and the indoor level is –45 dBm. Indoor UWB operations in this band will be limited to –51.3 dBm.

[32] Study on 2700-2900 MHz Frequency Band Sharing Between Existing Aeronautical Radar Equipment and Planned Digital ENG/OB and digital Aeronautical Telemetry Services, EUROCONTROL, Edition Date 29/05/2001.

**FSS**. These 4-GHz earth stations are used to receive downlink transmissions from geosynchronous satellites for a variety of applications including voice, data, and video services for Government agencies. NTIA examined interactions with FSS systems employing antenna elevation angles of 20 degrees and 5 degrees. NTIA used an I/N protection criterion of –10 dB based on a general discussion of factors affecting the sensitivity of digital communication systems. Only the level proposed for UWB indoor operation at 30-meter heights exceeds the calculations for protection of receivers in the fixed satellite service with an elevation angle of 8°. Indoor UWB operations in this band will be limited to -51.3 dBm. The level computed for protection of FSS receivers with an elevation angle of 8 degrees was –67 dBm. For the proposed level of –51.3 dBm, the required separation distance to satisfy the protection criterion, a separation distance of 240 meters must be maintained. For the given scenario of an FSS earth station with an 8° elevation angle, if the separation distance is less than 240 meters, a 30 meter building would at least partially obstruct the 3 dB beamwidth of the mainbeam of the earth station antenna based purely on the geometry of the scenario. Hence the level –51.3 dBm is adequate.

**CW and Pulsed Radar Altimeters**. These systems provide pilots of civil and military aircraft and, through them, air traffic controllers with information on the height of an aircraft above ground level. NTIA's investigation demonstrated that UWB devices operating at the Part 15 general emission limits would not result in interference to these operations. For that reason, we have not investigated these systems in any greater detail.

**Microwave Landing Systems**. These systems are used for precision approach and landing of civilian and military aircraft. The MLS ground station supports navigation and guidance out to a range of 43 km at an altitude of 20,000 feet. NTIA stated that RF interference could lead to errors in the estimation of time intervals associated with beam passage of the MLS transmitting station's antenna beam.[33] It added that, depending on the frequency components of the error process and the aircraft flight control system guidance loop bandwidth, this could lead to the physical displacement of the aircraft relative to the desired approach path. NTIA added that the ICAO specified the maximum permissible interference power into a MLS receiver as –130 dBm to prevent this from occurring.[34] NTIA subtracted 4 dB from the ICAO threshold "to partition the UWB interference into the link budget," resulting in NTIA's maximum permissible UWB interference level of –134 dBm. NTIA employed a 5-dBi gain antenna, the maximum available to the aircraft at an angle of about 30 degrees below the horizontal. For the case of high PRF UWB undithered operations the predicted interference level is -54 dBm/MHz at a distance of 160 meters from the MLS. Due to the geometry of the MLS scenario, the predicted interference will occur in an annular ring around the MLS. The I/N calculated in this analysis provides enough protection margin for transient operations of GPR and imaging systems that would be necessary at this distance. The other UWB operational scenario is the low PRF GPR and imaging scenario. The analysis predicted that for low PRFs, a protection level of –45 dBm/MHz would be required for separation distances of 70 meters. As with the previous case, the predicted interference will occur in an annular ring around the MLS at 70 meters. As before, the I/N provided for in this analysis provides enough protection margin for transient operations of GPR and imaging systems that might be necessary at this distance.

However, upon further analysis, NTIA has concluded that the additional 4 dB of protection is not required and the UWB EIRP limit is –41 dBm/MHz will sufficient to protect MLS

[33] NTIA Special Publication 01-43, *supra*, at pg. A-17.

[34] International Standards and Recommended Practices Annex 10 to the Convention of International Civil Aviation, Volume 1 (Radio Navigation Aids) Fifth Edition, July 1996.

operations.

**TDWR**. These radars operate in the 5600-5650 MHz band and provide measurements of gust fronts, microbursts, and other weather hazards at for improving safety operations at major airports in the United States. They are located within 24 kilometers (15 miles) of airports and need to have a clear line-of-sight (LOS) at the runway to observe weather phenomena for aircraft approaches and landings. Indoor UWB operation is the only UWB operation not directly protected by the proposed limits. The proposed UWB EIRP level for this band is –41.3 dBm which is 8 dB above the calculated EIRP. To achieve the required protection for the TDWR, a UWB located in a 30-meter building would have to be located 1370 meters away. Given the 0.2° minimum elevation angle of the antenna mainbeam, the beam would only be 5 meters above the horizon. The building itself would at least partially obstruct the 3 dB beamwidth of the mainbeam and be the limiting factor along the given azimuth and not the UWB's EIRP. An elevation angle of greater than 1.25 degrees is required to clear a 30-meter obstacle at a distance of 1370 meters. Therefore, the geometry of the TDWR is the limiting factor for this scenario, not the EIRP of the UWB.

## Indoor Use of UWB

The possibility of restricting most applications of UWB technology to indoor use but imaging and vehicular radar applications was not considered in the NTIA analysis. Thus, the constraints NTIA's analysis originally concluded were necessary to protect government receivers from outdoor use of UWB devices must be reformulated to account for the indoor use of UWB devices and the inherent additional expected propagation attenuation. This is done by simply adding a term for the value of expected building attenuation as a function of frequency to the link budget analysis model described earlier. NTIA analyzed UWB devices operating in-doors at heights of 2 meters (roughly equivalent to ground level) and 30 meters (roughly equivalent to the tenth floor in a typical suburban, office building) and calculated the maximum allowable UWB EIRP. The results of the analysis are summarized in Table 2. Table 7. Maximum UWB EIRP for UWB Use Indoors.

**Table 8 Maximum UWB EIRP for UWB Use Indoors.**

| System | Freq (MHz) | Max UWB EIRP (dBm/MHz) UWB Indoors 2 m | Max UWB EIRP (dBm/MHz) UWB Indoors 30 m | Average Building Attenuation Losses[35](dB) |
|---|---|---|---|---|
| DME, Interrogator | 960-1215 | -38 | Not Applicable[36] | 9 |
| DME, Transponder | 1025-1150 | -55 | -48 | 9 |
| ATCRBS, Transponder | 1030 | -35 | Not Applicable | 9 |
| ATCRBS, Interrogator | 1090 | -22 | -36 | 9 |
| ARSR-4 | 1240-1370 | -50 | -71 | 9 |
| SARSAT | 1544-1545 | -60 | -57 | 9 |
| ASR-9 | 2700-2900 | -37 | -57 | 9 |
| NEXRAD | 2700-2900 | -33 | -67 | 9 |

[35] NTIA Report 95-325, Building Attenuation, at pg. 43.

[36] "Not Applicable" indicates that the particular scenario would involve an airborne receiver at the same altitude as a UWB transmitter, which should not occur.

| System | Freq (MHz) | Max UWB EIRP (dBm/MHz) UWB Indoors 2 m | Max UWB EIRP (dBm/MHz) UWB Indoors 30 m | Average Building Attenuation Losses[35](dB) |
|---|---|---|---|---|
| Marine Radar | 2900-3100 | -44 | -45 | 12 |
| FSS, 20 degrees | 3700-4200 | -25 | -30 | 12 |
| FSS, 5 degrees | 3700-4200 | -39 | -65 | 12 |
| CW Altimeters | 4200-4400 | 26 | Not Applicable | 12 |
| Pulsed Altimeters | 4200-4400 | 26 | Not Applicable | 12 |
| MLS | 5030-5091 | -42 | Not Applicable | 12 |
| TDWR | 5600-5650 | -23 | -51 | 12 |

**UWB Interference due to Peak Emission Levels.** NTIA also performed a limited analysis of potential interference to SARSAT and FSS stations due to the peak level of the UWB transmitter. However, NTIA did not consider the proposed limits on peak power levels in the *Notice,* since their measurements did not show a need for such limits for analog systems and only very limited measurements were made on digital systems. No conclusion can be made from the peak power analysis due to the non-linear nature of the digital systems, unique error correcting schemes, and unknown characteristics of individual UWB systems operating in these bands. The actual impact to a digital wideband system from the peak power received from a UWB device will depend on many receiver parameters not generally available such as modulation scheme, and bit error rates. As a result, the peak values NTIA used for its analysis are far in excess of the levels the Commission proposed in the *Notice.*[37] Consequently, we do not envision interference problems from peak emissions from UWB devices if the peak power limits proposed in the *Notice* are embraced.

[37] The primary effect of the Commission's peak power limits as proposed in the *Notice* is that the peak power limit provides the restriction at lower PRFs while the average power limit provides the restriction at higher PRFs. .

## ATTACHMENT 2
## ASSESSMENT OF POTENTIAL INTERFERENCE TO THE PASSIVE SENSORS OPERATING IN THE 23600-24000 MHz BAND FROM SHORT RANGE RADAR SYSTEMS

(February 13, 2002)

Tables 1 through 4 provide link budgets to determine the maximum density of vehicles equipped with short range radar (SRR) systems that can be allowed before the interference of the passive sensor is exceeded. The methodology employed is consistent with that used in the filing to the Federal Communication Commission from the Short Range Automotive Radar Frequency Allocation Group (SARA) on January 30, 2002.

**Table 1.**

| Parameter | Value | Comment |
|---|---|---|
| Center Frequency (MHz) | 23800 | 23600-24000 MHz Band |
| Sensor Orbital Altitude (km) | 705 | AMSR-E Sensor Specification |
| SRR PSD EIRP (dBW/MHz) | -71.3 | Part 15 Level |
| LOS Elevation Angle (deg) | 35.2 | Based on altitude of 700 km and a 47.4 deg pointing angle from nadir |
| SRR Sidelobe Relative Gain (dB) | -23.2 | SRR Specification 0.66xLOS Elevation Angle SARA Proposal |
| Free Space Propagation Loss (dB) | -180.9 | Based on Slant Range of 1120 km |
| Atmospheric Loss (dB) | -1 | ITU-R Recommendation P.676 |
| Sensor Mean Antenna Gain (dBi) | 45.2 | AMSR-E Sensor Specification 46.7-1.5 dB |
| Received Power at the Sensor (dBW/MHz) | -231.2 | |
| Interference Threshold (dBW/MHz) | -183 | ITU-R Recommendation SA.1029-1 |
| Available Margin (dB) | 48.2 | Difference between received power at the sensor and the interference threshold |
| Maximum Number of SRRs | 66,069 | $10^{48.2/10}$ |
| Sensor Field Of View (km$^2$) | 427 | AMSR-E Sensor Specification |
| Maximum SRR Density (SRRs/km$^2$) | 155 | 66069/427 |

| | | |
|---|---|---|
| Maximum Vehicle Density (Vehicles/km$^2$) | 39 | Only 4 of the 8 SRRs mounted on any one vehicle will be transmitting at any given time |

**Table 2.**

| Parameter | Value | Comment |
|---|---|---|
| Center Frequency (MHz) | 23800 | 23600-24000 MHz band |
| Sensor Orbital Altitude (km) | 833 | AMSU-A Sensor Specification |
| SRR PSD EIRP (dBW/MHz) | -71.3 | Part 15 Level |
| LOS Elevation Angle (deg) | 90 | Nadir Pointing |
| SRR Sidelobe Relative Gain (dB) | -30 | SRR Specification LOS Elevation Angle > 45 deg SARA Proposal |
| Free Space Propagation Loss (dB) | -178.4 | At nadir |
| Atmospheric Loss (dB) | -1 | ITU-R Recommendation P.676 |
| Sensor Mean Antenna Gain (dBi) | 34.5 | AMSU-A Sensor Specification 36- 1.5 dB |
| Received Power at the Sensor (dBW/MHz) | -246.2 | |
| Interference Threshold (dBW/MHz) | -183 | ITU-R Recommendation SA.1029-1 |
| Available Margin (dB) | 63.2 | Difference between received power at the sensor and the interference threshold |
| Maximum Number of SRRs | 2,089,296 | $10^{63.2/10}$ |
| Sensor Field Of View (km$^2$) | 2,073 | AMSU-A Sensor Specification |
| Maximum SRR Density (SRRs/km$^2$) | 1,008 | 2089296/2,073 |
| Maximum Vehicle Density (Vehicles/km$^2$) | 252 | Only 4 of the 8 SRRs mounted on any one vehicle will be transmitting at any given time |

**Table 3.**

| Parameter | Value | Comment |
|---|---|---|
| Center Frequency (MHz) | 23800 | 23600-24000 MHz band |
| Sensor Orbital Altitude (km) | 825 | ATMS Sensor Specification |
| SRR PSD EIRP (dBW/MHz) | -71.3 | Part 15 Level |
| LOS Elevation Angle (deg) | 90 | Nadir Pointing |
| SRR Sidelobe Relative Gain (dB) | -30 | SRR Specification LOS Elevation Angle > 45 deg SARA Proposal |
| Free Space Propagation Loss (dB) | -178.3 | At nadir |
| Atmospheric Loss (dB) | -1 | ITU-R Recommendation P.676 |
| Sensor Mean Antenna Gain (dBi) | 31 | ATMS Sensor Specification 32.5-1.5 dB |
| Received Power at the Sensor (dBW/MHz) | -249.6 | |
| Interference Threshold (dBW/MHz) | -183 | ITU-R Recommendation SA.1029-1 |
| Available Margin (dB) | 66.6 | Difference between received power at the sensor and the interference threshold |
| Maximum Number of SRRs | 4,570,882 | $10^{66.6/10}$ |
| Sensor Field Of View ($km^2$) | 4,427 | ATMS Sensor Specification |
| Maximum SRR Density (SRRs/$km^2$) | 1033 | 4570882/4427 |
| Maximum Vehicle Density (Vehicles/$km^2$) | 258 | Only 4 of the 8 SRRs mounted on any one vehicle will be transmitting at any given time |

**Table 4.**

| Parameter | Value | Comment |
|---|---|---|
| Center Frequency (MHz) | 23800 | 23600-24000 MHz band |
| Sensor Orbital Altitude (km) | 816 | CMIS Sensor Specification |
| SRR PSD EIRP (dBW/MHz) | -71.3 | Part 15 Level |
| LOS Elevation Angle (deg) | 33.2 | Based on altitude of 816 km and a 47.9 deg pointing angle from nadir |
| SRR Sidelobe Relative Gain (dB) | -21.9 | SRR Specification 0.66xLOS Elevation Angle SARA Proposal |
| Free Space Propagation Loss (dB) | -182.5 | Based on Slant Range of 1331.6 km |
| Atmospheric Loss (dB) | -1 | ITU-R Recommendation P.676 |
| Sensor Mean Antenna Gain (dBi) | 52 | CMIS Sensor Specification 53.5-1.5 dB |
| Received Power at the Sensor (dBW/MHz) | -224.7 | |
| Interference Threshold (dBW/MHz) | -183 | ITU-R Recommendation SA.1029-1 |
| Available Margin (dB) | 41.7 | Difference between received power at the sensor and the interference threshold |
| Maximum Number of SRRs | 14,791 | $10^{41.7/10}$ |
| Sensor Field Of View ($km^2$) | 394 | CMIS Sensor Specification |
| Maximum SRR Density ($SRRs/km^2$) | 38 | 14791/394 |

| | | |
|---|---|---|
| Maximum Vehicle Density (Vehicles/$km^2$) | 10 | Only 4 of the 8 SRRs mounted on any one vehicle will be transmitting at any given time |

As part of the SARA filing anticipated vehicle densities were provided for three scenarios as shown in Table 5.

**Table 5.**

| Scenario | Vehicle Density |
|---|---|
| Highway | 123 vehicles/$km^2$ |
| Suburban City | 330 vehicles/$km^2$ |
| Worst Case | 453 vehicles/$km^2$ |

Table 6 summarizes the maximum vehicle density for the different passive sensors.

**Table 6.**

| Passive Sensor | Maximum Vehicle Density |
|---|---|
| AMSR-E | 39 vehicles/$km^2$ |
| AMSU-A | 252 vehicles/$km^2$ |
| ATMS | 258 vehicles/$km^2$ |
| CMIS | 9 vehicles/$km^2$ |

As shown in Table 6, the maximum vehicle density required to exceed the interference threshold for the AMSR-E and CMIS sensors is well below the anticipated vehicle densities shown in Table 5. Therefore additional attenuation of the SRR signal is necessary. In order to achieve this additional attenuation the emission levels of the SRRs must be reduced below 24 GHz. An additional 10 dB of attenuation would increase the maximum vehicle density for the AMSR-E to 387 vehicles/$km^2$ and for the CMIS to 94 vehicles/$km^2$. These vehicle densities are closer to the range of the anticipated vehicle densities shown in Table 5.

Based on the results of the analysis, the SRR emissions in the direction of the passive sensors below 24 GHz must be reduced by at least 10 dB. This can be accomplished in one of the following ways:

1) locate the lower -10 dB point of the SRR wideband emission spectrum above 24 GHz (this would also meet the intent of international footnote S5.340 and U.S. footnote 246);

2) lower the SRR antenna gain by an additional 10 dB, relative to the mainbeam gain, at all angles greater than 30 degrees above the horizontal;

3) lower the entire wideband emission spectrum by 10 dB through spectral shaping;

4) establish limits on the permitted duty cycle of each SRR.

# Summary of UWB EIRP Limits (dBm/MHz at antenna output) & Use Constraints – Atch 3

(February 13, 2002)

| Bands (MHz)/Bandwidth/Use | Imaging[1] | Indoors[2] | Outdoors (Includes Peer to Peer)[2] | Vehicular | Public Safety Through-wall & Surveillance Sys |
|---|---|---|---|---|---|
| 0.009-960 | Part 15.209 | | | | |
| 960-1,610 | -65.3 | -75.3 | -75.3 | -75.3 | -53.3 |
| 1,610-1,990 | -53.3 | | -63.3 | -61.3 | -51.3 |
| 1,990-3,100 | -51.3 | | -61.3 | -61.3 | -41.3 |
| 3,100-10,600 | -41.3 | | -41.3 | -61.3 | -41.3 |
| 10,600-22,000 | -51.3 | | -61.3 | -61.3 | -51.3 |
| 22,000-24,000 | -51.3 | | -61.3 | -51.3 | -51.3 |
| 24,000-29,000 | -51.3 | | -61.3 | -41.3 | -51.3 |
| 29,000-31,000 | -51.3 | | -61.3 | -51.3 | -51.3 |
| Above 31,000 | -51.3 | | -61.3 | -61.3 | -51.3 |
| NTIA/FCC Coordination Required3 | Yes | No | | No | Yes |
| Lower –10 dB point | Above 3.1 GHz | | | Above 24 GHz | Above 1.99 GHz |
| Upper –10 dB point | Below 10.6 GHz (Or Below 960 MHz for Imaging Only)[1] | | | Below 29 GHz | Below 10.6 GHz |
| Directional Antennas with min suppression of [25] dB below max gain at angles 35° from main beam centerline. | No | | | Yes[4] | No |
| Measurement shall not exceed EIRP (dBm) in resolution bandwidth of 1 kHz or > @ 3 m for 1164-1240 & 1559-1610 MHz. | -75.3 | -85.3 | | -85.3 | -63.3 |
| Law Enforcement, Fire Fighting and Emergency Rescue Users Eligible for Part 90 | May Use GPRs & Through-wall & Wall Imaging | No User Restrictions | | | May Use Through-Wall & Surveillance Systems |
| Scientific Research Institutes, Commercial Mining, or Construction Companies & Utililities/Industrial Entities (Surveillance Systems only) eligible for Part 90. | May Use GPRs & Wall Imaging | | | | Utility & Indust Entities (Pub Util & Indust, elig for Part 90) May Use Surv. Syst |
| Medical users under supervision of licensed health care practitioner. | May Use Medical Imaging | | | | |

1 Imaging systems may also operate below 960 MHz as long as the upper –10 dB points on their emission spectra are less than 960 MHz.
2 Tags, data transfer, and voice are included in the "Indoors" and "Outdoors Peer to Peer" categories above but are not part of Imaging, Vehicular, Public Safety, Through-wall, or Surveillance system categories.
3 Coordination is to be addressed within 15 working days of the date of the UWB use request or it will be automatically approved.
4 NTIA's analysis indicates there is interference to the earth exploration satellite service (EESS) passive satellite receivers from automotive radars if they operate at 24.125GHz. The analysis was based on 22 to 23 db antenna discrimination at elevation angles above 30 degrees above the horizon. The analysis concluded that the vehicular radar emissions must be least 35 dB down (at elevation angles above 30 degrees above the horizon) the current Part 15 level at 24 GHz to resolve the potential interference problem. Currently, it has been agreed that the radar system could attain attenuation of 25 dB from the main beam gain at elevation angles of 30 degrees or greater above the horizon. It is recognized that radars will be placed on automobiles over a period of time and a phased in approach to attain the necessary attenuation is warranted. Therefore, to attain this additional 10 dB and based on a 5/4 year development cycle, it would appear that the attenuation of 25 db is satisfactory beginning in 2005; increased to 30 db by [2010], and further increased to 35 dB by [2014]. Methods to obtain this 10 dB of attenuation at 24 GHz could include but not limited to: spectral shaping, lower duty cycle, reduced power, and increase antenna discrimination.